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AN INTEGRATED SYSTEM FOR COAL HANDLING, BENEFICIATION, TRANSPORTATION, AND COMBUSTION OF CANADIAN COALS

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AN INTEGRATED SYSTEM FOR COAL HANDLING, BENEFICIATION, TRANSPORTATION, AND COMBUSTION OF CANADIAN COALS

by

M.W. Mikhail* and J.K. Szymanski**

ABSTRACT

An integrated system for mining, handling, beneficiation, transportation and utilization is outlined with an emphasis on beneficiation and transportation. The system handles the coal in slurry form from mine stage up to utilization. Coal beneficiation includes two stages: state-of-the-art coarse coal technology to remove both ash and sulphur, thereby reducing reject dewatering costs followed by deep cleaning of clean coal from the first stage to produce a high quality product for direct combustion as a coal-water slurry. The proposed integrated system would minimize the need for dewatering and drying, improve safety in mining, handling and storage and meet environmental regulations. It is also expected to reduce the overall cost/M kJ for power generation. New CANMET pilot facilities in Devon, Alberta will be used to process coals to lower ash and sulphur than presently practiced and to characterize coals that are amenable for deep cleaning and to produce coal-water slurry for pipelining and combustion tests. The overall objective is to emphasize high coal quality and reduce transportation cost.

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UN SYSTÈME INTÉGRÉ DE MANIPULATION, DE VALORISATION, DE TRANSPORT ET DE COMBUSTION DES CHARBONS CANADIENS

par

M.W. Mikhail* et J.K. Szymanski**

RÉSUMÉ

Le présent article traite globalement d'un système intégré en exploitation minière, de manipulation, de valorisation, de transport et d'utilisation, avec un intérêt marqué sur la valorisation et le transport. Le système manipule la boue de charbon de la mine jusqu'à son utilisation. La valorisation du charbon inclut deux étapes: premièrement, une technologie moderne pour enlever la cendre et le soufre du charbon grossier, de façon à réduire les coûts dûs au rejet de déshydratation, et deuxièmement, une épuration à fond du charbon épuré provenant de la première étape, dans le but de produire un produit de haute qualité pour la combustion directe de la bouillie charbon-eau. Le système intégré tel que proposé devrait minimiser le besoin de déshydratation et de séchage, améliorer la sécurité lors de la manipulation, de l'entreposage et de l'exploitation minière en général, et enfin satisfaire la réglementation environnementale. Il est prévu également que ce système réduira le coût global (en M kJ) inhérent à la production d'électricité. Les nouvelles installations pilotes du CANMET à Devon en Alberta seront utilisées pour transformer les charbons à des niveaux inférieurs en cendre et en soufre, par comparaison à ce qui se fait habituellement, pour caractériser les charbons qui sont propices à l'épuration à fond et enfin pour produire une bouillie charbon-eau pour pipeline et pour des tests en combustion. Le but global est de parvenir à un charbon de haute qualité et de réduire les coûts de transport.

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CONTENTS

	Page
ABSTRACT	1
RESUME	11
INTRODUCTION	1
COAL MINING AND HANDLING	2
Role of Hydraulic Mining	3
COAL BENEFICIATION	4
High Ash Content	6
High Sulphur	7
TRANSPORTATION	8
COAL COMBUSTION	10
INTEGRATED SYSTEM FOR COAL HANDLING, BENEFICIATION, TRANSPORTATION, AND COMBUSTION	13
Safety	14
Economy	14
Environment	15
Limitation of an Integrated System	16
Beneficiation	17
Washability Characterization	18
State-or-the-art Technology	19
Deep Cleaning	19
Pilot Plant Role in Process Development	19
Transportation and Handling	20
CONCLUSION	22
REFERENCES	23

FIGURES

No.		
1.	Tariffs as a function of time, between pipeline and railway transportation	26
2.	An integrated system for coal handling, beneficiation, transportation, and combustion of coal water mixture	27
3.	Deep cleaning process development	28

INTRODUCTION

Due to the high transportation cost between producing mines in western Canada and Ontario, most of central Canada's needs are met by imported coal from the U.S. Metallurgical coal produced in western Canada is destined for export while thermal coal, mostly consumed locally (2 Mt shipped to Ontario), with limited amount for export. The Maritimes production of thermal and metallurgical coals are essentially for local market with limited surplus for export.

Estimated Canadian coal reserves are 120 billion tonnes, of which about 80% are located in Alberta and British Columbia. Canadian coal production in 1986 was estimated at 58 Mt (1), of which approximately 26 Mt were used at mine mouth generating plants. The remaining 32 Mt received extensive preparation prior to transport to distant markets for thermal and metallurgical use (mostly to the Pacific rim countries). Increase in metallurgical coal production is expected to be minimal, however, most of the increase in the total production would be a result of possibly accelerated increase in thermal coal production, depending on the increase in oil prices above present level.

Present mining costs of Canadian coals are low, resulting in an acceptable production cost as compared with other producing countries such as Australia and South Africa. However, the transportation cost of Canadian coal from mine site to either tide water or to central Canada can increase the cost by as much as 50%. The Canadian future export market is expected to be mostly to the Pacific rim countries with a potential market to western Europe. Present competitors are Australia, South Africa, U.S., and Poland. Transportation cost is seen to be a major factor in Canada's ability to compete on the international market. Presently, coal is transported by unit trains to the west coast and its cost is expected to increase/depending on inflation and various economic factors by the year 2000. One alternative to unit train transportation is slurry pipeline which

can keep transportation cost from being greatly influenced by inflation rate as in the case of rail transportation.

The cost of burning oil (based on 1984 prices) for power generation is approximately 2.5 times that of using coal to produce the same amount of electricity. In spite of that economic advantage, coal is still not widely used for power generation. Oil costs less than coal in handling, preparation and waste disposal. Environmental concerns related to transporting, handling and utilizing coal such as dust, fly ash, acid rain (SO_2) and NO_x are limiting the expansion in coal use for power generation. This paper investigates the feasibility of an integrated system to make coal competitive to oil as a source of energy and also to overcome present disadvantage of transporting coal to a distant market.

COAL MINING AND HANDLING

During the period 1960-1980, tonnages of coal recovered by surface mining increased from 15 per cent to about 90 per cent of the Canadian total production (3). The average annual output per strip mine operation in 1986 was 2.2 Mt. In 1986, production from surface mines totalled about 52.4 Mt, of which 98% were originated from western Canada open pit mines. In most cases coal is transported by trucks to a central handling station or preparation plant. Canadian underground coal extraction is normally carried by continuous long wall mining and conventional room and pillar methods. In roadways near working faces, belt conveyors are used for bulk transport. About 50% of run of mine (rom) coal output still reaches the main shafts by mine car haulage or wide use of diesel powered equipment.

ROLE OF HYDRAULIC MINING

Presently about 85% of the Maritimes production is from underground operation, mostly from under sea mines. Also, it is estimated that within 25 years, up to 80% of western Canada coal production will be won by underground techniques. Although western Canada's coal resources are considerable, they are in some cases locked in severely distorted, steeply piching and faulted seams of variable thickeness. Consequently, their economic extraction poses serious engineering problems (4). One site specific solution to the problem is to apply hydraulic methods to underground mining. The technology is extremely flexible and allows mining of highly inclined seams with high gas emission which is liable to sudden outburst. It is entirely possible that in the future, mining technology in coal extraction will be revolutionized by integrated hydraulic techniques to mine and transport raw coal to preparation plant.

A comprehensive hydraulic mining operation will involve the use of water jets to cut and break the coal, as well as hydraulic transport of r.o.m coal from the mine to preparation plant. A pipeline from coal face to preparation plant can eliminate dust, noise and other problems that are potential hazards in typical underground coal mining operation. Dust concentration in the hydromine air does not exceed 0.25 - 0.50 mg/cm^3. There are no reported accidents of methane or coal dust explosions associated with hydraulic mining operation in Canada or abroad. However, spontaneous combusiton occured in seams near to the surface due to air passage through fissures in presence of water. The economics of underground hydraulic mining, from both the capital and operating point of view are reported to show considerable savings over conventional underground mining methods (5) except for flat and gently dipping (up to 15 degrees) and intermediate thickness (1.5 to 3.0 m seams). Here the use of conventional systems (room and pillar method) and self-advancing supports (long wall method) has an economic edge (5, 6). The modern equipment used in hydraulic mining operations does not require constant worker attendance at the coal face. Further

progress in technique and technology will extend the application of hydraulic mining to surface operations.

The integration of hydraulic coal mining, crushing and slurry pipelining is still in the early stages of development. An integrated operation was being used successfully on a soft and thick Balmer seam, Westar Ltd., B.C. (7). Coarse coal pipeline technology has been tested in recent years and is working successfully in at least one mine, Laveridge - long wall mine in West Virginia, U.S.A. - since 1980 (8). Some limitations still exist and need to be resolved before wide application of an integrated system. Seams with poor roofs and floors are not suitable for hydraulic mining operations. Attrition during pumping and pipelining may generate fines that increases the cost of preparation and may decrease the clean coal recovery in a conventional preparation plant. Bulk storage of coal slurry before being fed to the preparation plant is not as easy as storing dry raw coal. In spite of these difficulties, the advantages of hydraulic system for mining and pipelining to the preparation plant are expected in most cases to out-weigh the disadvantages.

COAL BENEFICIATION

Presently, Canadian thermal and metallurgical coals are upgraded to between 10 and 15% ash and between 7 and 10% ash respectively. The beneficiated coal is usually transported for a distance of 1000 km or more either to central Canada or the west coast for export. Transportation costs are substantial and as a result beneficiation plays a mjaor role in reducing the cost/tonne.

Canadian coal characteristics related to coal beneficiation technology can be identified as follows (9):

1. Eastern coals have high sulphur contents, essentially similar to those of eastern United States. Ash removal is easily achieved by beneficiation resulting in low ash content, however, sulphur removal is limited. Two preparation plants are in operation on Cape Breton Island to produce metallurgical and thermal coals. Preparation of thermal coal is mostly required to reduce sulphur content to 2% or less. However, some coals may contain over 2% organic sulphur and finely disseminated pyritic sulphur. These sulphur forms are not easy to separate by density separation. Levels of preparation applied at Cape Breton Island range between 3 and 4*.

2. Rocky Mountain coals are included in highly sheared seams which have been subjected to rapid coalification. The high friability of these coals (20 to 60% by mass of minus 0.6 mm) means that degradation during mining, handling and preparation cannot be avoided. Widely varying geological structures and differing exposure to both the atmosphere and ground water result in differential oxidation with consequent variability in the performance of flotation process. Three thermal coal preparation plants and five metallurgical plants are in operation. Thermal coal cleaning is usually focussed on coarse coal (plus 10 mm) with the raw coal fines (minus 10 mm) being blended with coarse clean coal. This is because many mountain and some foothills coals show a decrease in ash content as the coal particle size decreases. This reflects the friability of

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*level of preparation is a measure of intensity of work done on a raw coal and high levels are expected to improve clean coal quality but they also increase the cost of preparation (one to six levels) (10).

the coal substance. The level of preparation applied to thermal coals range between 3 and 4. For metallurgical coals, multi-stage cleaning is necessary (levels 4 to 6) to produce clean coal with 7 - 10% ash.

Foothills high volatile bituminous coals are frequently interbedded with soft shales and bentonitic clays that are released during washing. The amounts of minus 0.6 mm fraction represent 20 - 30% by mass of the raw coal; approximately 50% of this is clay. The level of preparation ranges between 4 and 5 and the cost of dewatering fine reject is usually high.

4. Plains coals include sub-bituminous coals and lignities. These coals are relatively low in ash, high in inherent moisture and traditionally are used at mine mouth power generation plants without preparation. Studies are underway to find ways to simultaneously reduce the moisture content and upgrade coal quality (11). Cleaning would be considered if low rank coals are to be transported to a distant market. However, that possibility is not expected before 1990.

Widespread export of thermal coal is only feasible if Canadian supplies can provide a coal which is competitive on the international energy market place without contravening any local environmental concerns. The challenge is to produce a clean, low-ash, low sulphur coal with higher heat value/kg than presently available (above 25000 kJ/kg).

HIGH ASH CONTENT

Western Canada thermal coals are presently cleaned to 10% ash or higher. Further reduction in ash (below 10%) would result in considerable loss in thermal recovery. Ash in clean coal includes inherent ash, middlings particles and interbedded

clays. The inherent ash in western thermal coals is usually between 3 and 6% (for high volatile bituminous coals). Because the amounts of middlings in western coals are substantial as compared to eastern coals, removing relatively high ash middlings particles from clean coal would significantly decrease thermal recovery. The problem is compounded when some interbedded clays in particles coarser than 0.6 mm report to the clean coal fraction.

HIGH SULPHUR

Maritimes coals are known for their high sulphur content (2 - 6%). Pyritic sulphur represents 30 - 70% of the total sulphur and in most cases is finely disseminated. Sulphur reduction can be achieved by partial removal of pyritic sulphur depending on the pyrite particle size and distribution.

Lowering the ash and/or sulphur contents to levels below current practice will require reduction of the average particle size to literate more high ash and/or pyritic sulphur particles. However, a reduction in average particle size will exponentially increase the dewatering and drying cost which presently represent up to 50% of the total preparation cost. A method that can utilize coal slurry with minimum dewatering may improve the chances of deep (below practiced ash or suphur levels) cleaning of coal without significantly increasing preparation cost. Dense coal slurry combustion presents the possibility of significantly lowering ash and/or sulphur contents without having to pay for dewatering and drying cost of fine coal.

Presently, coal beneficiation cost represents 20% or less of the total cost/tonne of western thermal coal (f.o.b. Vancouver). Further reductions in ash levels-however they are achieved-will increase the beneficiation cost and can only be justified if accompanied by a reduction in transportation cost. The low ash and/or sulphur clean coal would be both environmentally and economically acceptable. Some of the processes that may be considered for deep cleaning are two stage flotation, oil agglomeration, high intensity magnetic separation,

electrostatic separation, heavy medium cyclones, and low cost chemical cleaning. These processes would not replace presently used beneficiation processes based on density separation and rougher flotation but would be considered as an additional stage after density separation to improve clean coal quality.

In summary, deep cleaning of coal to 2 - 8% ash and less than 1% sulphur content will result in the following advantages:

1. An environmentally acceptable source of energy that would produce minimum of toxic gases and fly ash.

2. Increased heat value/tonne would reduce tranportation cost which presently represent up to 50% of total cost/tonne and in turn make Canadian coals more competitive on the export market.

TRANSPORTATION

In 1985, 27.0 megatonnes of coal were exported (1). further demand for high quality metallurgical coal is uncertain and increase in export of thermal coal is partly dependent on increase in oil prices. Ontario need of 14.3 megatonnes can easily be met by low sulphur western Canadian coals. However, the transportation cost is approximately five times greater than that of American coals (1). Although the present unit train systems of moving coal to sea board or central Canada is partly considered to be one of the worlds most efficient, transportation cost pose a selous threat to Canada's potential for supplying a significant portion of the world thermal coal requirements.

As rail traffic increases, in the areas producing large amount of coal, long distance coal slurry pipeline transportation becomes attractive as a possible alternative. A study to evaluate pipelining thermal coal from Coalspur, Alberta to Canada's west coast (12) took as a basis for conceptual design a

pipeline capacity of 10.2 Mt/year and an expansion case that handles 18.2 Mt annually. The estimated total pipeline length was 1016 km. Economic evaluation indicated that where slurry systems with a throughput of 15 Mt/year could be operational in the 1990's. The study's estimated costs for rail and pipeline transportation are not valid today due to changes in energy need and prices that are totally different from that of 1982. About 75% of the cost/tonne/km of pipeline transport is capital, thus only 25% is subject to inflation. An example case for transportation of 4.5 million tonne (5 million ton)/year (Fig. 1) shows the impact of the difference in tariff escalation between pipeline and rail transportation for 5% inflation.

In the U.S., the current average cost for rail delivery of coal by unit train is 1.65 cents (US)/tonne/km. The current rate charged by the only operating coal pipeline in the U.S. (Black Mesa pipeline), 440 km long, 0.46 m in diameter is 0.9 cents (US)/tonne/km. Slurry transport of coal as mixture with water, carbon dioxide, methanol, or other liquid through a pipeline also costs less than rail (13). However, slurry pipeline transportation has limitations, some of which are summarized as follows:

1. Design capacity: excessive overloading can accelerate wear and below capacity loading causes settling (dragging effect) which in turn increase wear of lower section of the pipe.
2. The size distribution required for long distance transportation of the stable slurry (minus 1.2 mm) is incompatible with that normally required for metallurgical coals used in charging conventional coke ovens.
3. Complete drying of finely graded coal to required surface moisture content of 10% can be costly both in capital and operating expenditure.
4. Water availability for slurry preparation and water clarification and disposal at the end of the pipeline.
5. A slurry pipeline is dedicated to transport a single product such as coal while rail is versatile and somewhat flexible in capacity.

Current slurry pipeline technology is geared to a power plant at the end of the pipeline where fine coal in slurry form is dewatered to a surface moisture content between 10 and 14% before combustion. The main disadvantage of slurry pipelining has been the difficulty in the dewatering of the fine coal slurry after hydraulic transportation. Thermal drying is required for fine coal (<3.15 mm) to achieve 10 - 14% surface moisture (14). The dewatering and drying cost of fine coal represent about 50% or more of total slurry transportation cost depending on preparation of the superfines and the length of the pipeline. This dewatering cost percentage decreases (as a percentage of total cost) with an increasing length of the pipeline, and is significant for distances more than 500 km pipeline (14).

When the export potential of a fine coal is considered, it is immediately clear that handling the fine coal destined for export after dewatering and drying is not simple and can cause several problems in stockpiling, loading and unloading ships. If fine coal is dried enough for handling, it might generate dust problems. However, leaving coal with higher moisture increases marine transportation cost and might create different handling problems in loading and unloading such as freezing in winter time. Canadian coals are known to be friable and attrition during pipelining could generate even finer fractions and further increase dewatering costs and handling problems.

COAL COMBUSTION

Coal combustion process selection is dependent on coal's physical and chemical properties, environmental regulations and economic factors. Stoker boilers can be used for boilers with up to 80 MW capacity. Moisture content, ash content and ash characteristics significantly affect the performance of the stokers. For large coal fired boilers (over 25 MW), pulverized coal (>75 μm) can be used. Pulverized coal boilers performance is influenced by ignition, flame stability and ash

characteristics. Fluidized bed combustion can tolerate variations in ash content and handle lower grades of coal. Sulphur dioxide (SO_2) can be reduced during the combustion process by feeding limestone with the coal. Also, the relative low operating temperature in the bed helps to reduce the formation of nitrogen oxides.

An Electric Power Research Institute (EPRI) investigation of the impact of coal cleaning on the cost of new coal-fired power generation plants showed net electricity generation cost savings for new, large plants when coal cleaning was used (15). Additional savings are realized through the improvement in plant availability resulted in an estimated additional saving of $1.5 million/year. Utah Power and Light Company has estimated the availability improvement of 4.5 and 6.7% if coals of 11.5 and 14% ash respectively, were cleaned to 8.4% ash (16). Reduced ash content would lower the precipitation of mineral matters on the boiler walls and in turn reduce required down time for maintenance. Also improved heat value (kJ/kg of coal) would reduce capital investment for boilers as high heat value clean coal requires a small steam generator and reduce flue gas desulphurization system.

Acid Rain is related to the burning of high sulphur coals through sulphur and nitrogen oxides released to the atmosphere. In addition trace elements such as sodium, chlorine and mercury can cause significant problems both during combustion and after combustion when released with fly ash. The higher the mineral matter in thermal coal (ash and sulphur) is the higher the costs associated with maintenance of boiler and the control of released gases (sulphur and nitrogen oxides) and fly ash with trace elements to the atmosphere. Emission standards for coal power generating plants in Canada are summarized as follows (17):

	Emission Limit	
	mg/Nm^3	ng/J
Particulate	116	43
Sulphur oxides	700	258
Nitrogen oxides	614	258

Emission control can take place before, during or after combustion or in any combination of these three models. Beneficiation of thermal coal before combustion can significantly reduce ash and sulphur contents in clean coal. Ash content in many coals can be reduced to 10-12% at thermal recoveries above 85%. It is generally possible to remove up to 40% of pyritic sulphur by normal washing practice and that up to 60% by using deep cleaning methods (16). Sulphur dioxide can be reduced during fluidized bed combustion by using limestone or dolomite. The process requires the addition of 30% of limestone and more in the case of dolomite by mass of the coal feed. Both organic and pyritic sulphur are broken down during combustion to sulphur oxides which emitted from the boiler as part of the other gaseous combustion products. Flue gas desulphurization (FGD) is used to control SO_2 released after combustion with lime or limestone as a scrubber.

Coal cleaning before combustion is the most economic method for emission control. It reduces both ash and pyritic sulphur and also improves coal thermal value. Presently, preparation costs in Canada ranges between $6 - $9/tonne of clean coal. However, coal preparation technology only removes part of the pyritic sulphur and none of organic sulphur. The remaining sulphur can be controlled during and after combustion. Coal cleaning followed by FGD appears to be the most economic approach and its cost is about half that of FGD alone (18). However, deep cleaning of coal to achieve required ash and sulphur levels may result in significant reduction of coal thermal recovery.

The trend to burn coal instead of oil is for economic reason rather than technical ones. Oil is easy to handle, store and burn with minimum of harmful gases released and left over residues as in the case of coal combustion. The conversion of boiler plant from oil to coal use requires coal handling and grinding system, flue gas treatment and handling of fly ash. Converting an oil boiler to burn coal may also reduce the boiler output by as much as 30%. The capital investment to convert an oil boiler to burn coal is substantial. The conversion can be

greatly simplified if coal is delivered and used in a form similar to oil, i.e. in a liquid form (19).

INTEGRATED SYSTEM FOR COAL HANDLING, BENEFICIATION, TRANSPORTATION, AND COMBUSTION

Soviet study (20) suggested that an integrated system for coal extraction and utilization including a hydraulic mining, transport and dense coal slurry combustion would reduce the cost of kw/h by 10% as compared with dry technology in mining, transportation and combustion. The proposed integrated system in this paper carries the Soviet suggestion a step further by including two stages of beneficiation to achieve high quality product. The integrated system would eliminate a number of steps between mining and utilization (Fig. 2). In mining, hydraulic excavation if applicable, would reduce costs associated with roof control, air circulation to remove methane gas and dust. Hydraulic transport of mined coal to preparation plant as coarse slurry would simplifies the overall coal handling and eliminates both the dust control problem and the need to dewater coal before feeding it to the preparation plant. In beneficiation, raw coal can be reduced to its optimum size for ash liberation and separation without having to pay a penalty for dewatering and drying the clean coal. Slurry transportation of fine coal in a pipeline and if required, on a ship as slurry up to the power plant with no requirement for costly dewatering and drying of fine coal. At the power plant, the need for storage area would be replaced by storage tanks and also coal pulverization would not be required as the coal already prepared earlier at the preparation plant before transportation.

The introduction of the integrated system would influence safety, economy and environment related to the production and utilization of thermal coal.

SAFETY

Added to high productivity characteristics, the hydraulic mining system under the proper conditions offers one of the safest methods of underground mining of coal. Some of these safety factors are: elimination of spark-ignition hazard, safe working condition for miners away from face, water partially dissolves methane and reduces the gas release hazard, reduces dust in atmosphere to less than 0.25 to 0.5 mlg/m^3 and minimum requirement for blasting (5,7). Handling coal in a slurry form would sharply decrease the risk of gas outburst underground and gas explosions in silos and ships. Also dust hazard on workers health would be eliminated as coal is in wet form from mining stage up to utilization.

ECONOMY

Presently, the approximate distribution of mining, preparation and transportation in the total cost F.O.B. Vancouver of thermal coal can be summarized as follows (21):

Mining	Coal Preparation	Transport
49%	17%	34%

These costs vary from one operation to another in regard to mining and coal preparation, however, transportation is dependent on distance from Vancouver. An integrated system that included mining, slurry pipeline, beneficiation and combustion could reduce the production cost of 1 kwhr of electric power by as much as 20 to 30% of total cost (22). Hydraulic mining increases productivity (10 to 50 tonnes/man-shift depending on geological conditions) and new hydraulic mining methods may further increase productivity by 1.5 times (23). Hydraulic mining also allows 1.3 to 1.5 higher level of mechanization than in conventional mines thus reducing the share of labour cost, provides better recovery of resources, reduces volume rate of fresh air for ventilation and requires a minimum of support settings in the working areas.

All of these contribute to reduction in overall mining costs. However, it is necessary to indicate that a limited number of mines are amenable to hydraulic mining.

The use of coarse coal slurry pipeline to transport mined coal from coal face to preparation plant would reduce underground development required to haulage and hoist coal. This also reduces ventilation and dust control requirements. In beneficiation, the cost of dewatering and drying represent up to 50% of total preparation cost. The integrated system requires only dewatering of reject and clean coal is delivered in a slurry form that needs limited dewatering. Thus dewatering and drying cost can be substantially reduced as a result of using the integrated system. Also, the integrated system would allow reduction in particle size to achieve more liberation and in turn produce better quality coal without having to pay to dewater and dry fine clean coal. Pipeline transport of coal slurry would reduce transportation cost in the long run as discussed earlier as compared with rail. Coal destined for export may cost more to ship as a slurry due to addition cost of transporting higher moisture content than in dry form.

The handling of coal from mine face to utilization in a wet form would minimize oxidation and eliminate spontaneous combustion and deliver coal for use with no deterioration in quality. It also allows flexibility in storage for long periods. The deep cleaning of coal would allow Canadian coals with higher quality and lower production and transportation cost to compete on the international market. Also reduction in total cost/1 kwhr of 20 to 30% makes coal utilization comparable or cheaper than nuclear power.

ENVIRONMENT

The use of an integrated system eliminates the public conception of dirtiness associated with coal mining, handling, transportation, and utilization. Each step in existing technology is a potential hazard for dust release. The wet

handling of coal in coal water mixture would make it in some ways as convenient as using oil. The integrated system also reduces the amount of water released to environment and in turn lower the risk of polluting water streams with black water.

The deep cleaning of coal lowers ash and sulphur contents than presently practiced. This in turn reduces the release of SO_2 and NO_x to the atmosphere and reduce requirements for scrubbers after combustion. Briefly, the integrated system would make coal more environmentally acceptable than presently perceived.

LIMITATION OF AN INTEGRATED SYSTEM

The integrated system appears to be an attractive approach for expanding coal industry. However, some limitations have to be addressed and evaluated before wide application of the system. Some of these limitations are:

1. Presently, metallurgical coal represent the majority of coal transported for long distance or destined to export market. The integrated system is more suited to thermal coal, particularly from the utilization point of view. Carbonization requires dry coal and very fine coal is not suitable to handle in dry form. However, it is technically feasible (in case of dense coal slurry) at the final destination that pellets be made out of the dense metallurgical coal slurry. Pelletization, however, would increase the cost/tonne by somwhere between $3 to $10.

2. Efficiency of separation of fine coal is usually lower than that of coarse coal. Deep cleaning of fine coal to achieve ash levels below 8 to 10% would mean lower mass and/or thermal recovery than when cleaning coarse coal at higher cutpoints. The magnetitude of reduction in thermal recovery would vary from one coal to another depending on coal washing characteristics. Reduction in recovery would increase cost/tonne of clean coal.

3. As suggested earlier, coal cleaning would include two stages:
coarse coal cleaning followed by deep cleaning. The deep cleaning stage produces the final product and fine reject and/or middlings. The under-product (reject or middlings) requires dewatering and costs would depend on amounts and its utilization or discard.

4. The application of an integrated system would require power plants that are either converted from oil or dedicated to burn coal-water slurry. None of these plants are in existence yet.

5. Converting oil boilers to burn coal would reduce an oil designed boiler to about 70% of its firing rate, depending on coal properties and environmental regulations (16). Furthermore, burning coal-water slurry with 25% water reduces the boiler efficiency by 3% or more as compared with burning dry coal.

6. The use of chemical additives to stabilize the coal-water slurry and fine particle size, along with high percentage of solids in the slurry may result in higher viscosity, that in turn increase pumping cost as compared with present technology for slurry transportation.

Coal-water coal slurry combustion is under intensive evaluation at different research centres (20) and it is beyond the scope of this paper to discuss or outline research programs in these areas of expertise. However, beneficiation and slurry transportation R & D possibilities, related to coal-water slurry, are discussed below.

BENEFICIATION

Increased level of beneficiation to produce cleaner product than presently practiced would increase preparation cost,

however, that increase could partly be compensated by reduction in dewatering and elimination of drying costs of clean coal. The resultant cost of preparation in proportion of total cost/tonne of thermal coal might not increase substantially. This has to be established through R & D work and cost effective study. The approach would mostly involve optimization of known technology toward a new application rather than developing a new one. The following is a suggested plan to investigate the feasibility of selected Canadian coals for deep cleaning and utilization in a slurry form:

1. Washability Characterization

   This involves stage crushing and grinding and followed by size, float-sink, ash and sulphur analysis, and surface properties of fine particles. The exercise here differs from the one practiced to establish washability data for relatively coarse cleaning where excessive reduction in size by crushing is avoided to wash coal as coarse as possible. The washability characterization would be carried out on a selected number of seams that might be amenable for deep cleaning, i.e. coal washability improves with reduction in size. The ojbective is to determine optimum size ranges at which a particular coal can be cleaned effectively for both ash and/or sulphur.

2. Generally, it is known that the coarser the size, the lower the cost of cleaning and losses to the reject. In fact, the cost per tonne of feed is a function of the number of particles per tonne. Thus, cleaning costs increase rapidly as the mean particle size becomes smaller. As a result, it is desirable to remove most of the impurities from coal particles as coarse as possible. This would reduce cost of reject dewatering and disposal and minimize losses of clean coal particles to reject. Depending on coal washability, a two-stage cleaning approach would be advisable (Fig. 3).

a) State-of-the-Art Technology: This involves processes presently practiced such as heavy medium systems, jig, water-only cyclones, tables and froth flotation. The objective is to lower ash and/or sulphur as much as possible (10% ash or less) at acceptable mass and thermal recoveries and produce clean coal for preparation of coal-water clean coal for preparation or for further cleaning in a second stage.

b) Deep Cleaning: This involves crushing and grinding clean coal from the first stage to achieve liberation of ash and/or sulphur from coal particles. Processes suggested to clean fine coal are single or two stage flotation, oil agglomeration and high intensity magnetic separation. The objective is to produce a clean coal with 4 to 10% ash and 1% or less sulphur, depending on coal amenability for deep cleaning, thermal recovery, economic factors related to the integrated system and market requirement.

Stage (a) would involve computer simulation of different processes based on coals washability data to select a flowsheet and predict quality of products. Stage (b) would require bench scale testing and mini-plant testing (150 kg/h) to explore parameters, quality of products, recovery, and limitation of deep cleaning.

3. Pilot Plant Role in Process Development

Scale up of testing is necessary to verify predictions and produce results simulating industrial scale operations. The comprehensive pilot plant facilities at the Coal Research Laboratory can be used to develop unit operations, to optimize product yield and quality, and to demonstrate the potential of existing and new or improved unit operations to achieve specific quality of products. Accumulated data from pilot plant tests are useful for plant design parameters and

carrying a realistic cost effective study. The pilot plant is required to produce sufficient clean coal samples for handleability, pipeline and combustion tests.

TRANSPORTATION AND HANDLING

Transportation and handling are the important link in the realization of an integrated system. The convergance of dense coal slurry through pipelines is in the way of becoming an industrial reality (25). However, extenive R & D work still is required before large scale industrial application. Moving dense coal slurry by pipeline requires knowledge of suspensions rheology, hydraulics, wear rates (corrosive or abrasive nature of the slurry), equipment performance and instrumentation.

Studies performed with various dense coal slurries revealed that they generally exhibit non-Newtonian behavior (26). A characteristic feature of dense coal suspensions is the phenomenon of occurrence of delayed elasticity (creep test), as well as relaxation of shear stresses at fixed strain (relaxation test). Further investiation is required to develop methods that allow the measurement of the degree of settling and the effect of coarse/fine ratio on dense coal slurry static and dynamic stability both on laboratory scale and in a process development unit. The investigation is essential to determine required velocities, slurry behaviour in storage tanks and necessary stabilizing additives.

In order to consider the dense coal slurry transportation as an option, parameters and relationships are to be defined to predict accurately the head losses that will occur under assumed conditions. Also, dense coal slurry will either increase or decrease their viscosity as they are worked by the shearing action of the pump or pipe system. Measurement of these phenomena for the viscoelastic dense coal slurry appear to be desirable. In the course of further research, methods of measuring the response of dense coal slurry to a suddenly applied force is needed. With an increased interest in long distance pipeline transport of non-Newtonian dense coal slurry, the

problem of longitudinal wave propogation during start-up or shut-down is important (27). Without knowing this parameter one cannot determine the pipeline start-up and shut-down time and neither can one compute the magnitude of forces and stresses during the first half-period in which the forces and stresses achieve their maximum. At the present time, there is not enough data to develop necessary equations to predict different parameters and pilot plant studies are necessary prior to design work.

It appears that the viscosity-reducing effects of various additives to dense coal slurry require further development particularly in relation to specific Canadian coals. The slurries would include chemical additives to stabilize the suspension and improve the flow characteristics during transport. Also in order to be treated as a liquid, the dense coal slurry needs to be non-settling or stable or is easy to mix by agitation. For this reason, transportation and storage without or minimum agitation is aimed for in the process of utilizing such slurries. Further studies are required to give the theoretical bases for particle size distribution curves which are useful guides for preparation of highly-loaded slurries that would be amenable for stable suspension.

The overall objectives of a R & D program on dense coal slurry transportation is to produce a slurry that exhibit three important properties: high coal loading, low viscosity and stable during long term storage or can be easily agitated. Optimization to achieve the desirable slurry characteristics requires extensive pilot plant testing. The existence of slurry pipeline facilities at the Saskatchewan Research Council in Saskatoon with pipeline loops from 25 to 500 mm diameter pipes provide a source of experimental work for creation of dense coal slurry data banks. This data base, where possible, should contain costing parameters to aid in dense coal slurry pipeline design optimization.

CONCLUSION

The implementation of an integrated system from mine face to power plant would enhance Canadian coals chances to compete with oil and nuclear power and on the tight international market. Hydraulic mining and transport to preparation plant are an established and proven technology. Coal beneficiation by deep cleaning of fine coal and dense coal slurry transportation require further R & D work. The approach would mostly involve optimization of known technology toward a new application rather than developing a new one. This can be achieved by characterizing coal seams amenable for deep cleaning, process development of two stage beneficiation by applying coarse cleaning technology followed by deep cleaning stage to produce high quality clean coal. The comprehensive pilot plant facilities at the Coal Research Laboratory can be used to develop unit operations to optimize product yield, quality and demonstrate the potential of existing, improved or new technology to achieve specific quality of products. Pilot plant products would be used for slurry pipeline loops and combustion tests. Research and development on dense coal slurry needs knowledge of suspension properties (% solids, viscosity, etc.), hydraulics, wear rates, equipment performance, and instrumentation. This can be achieved by testing in available pipeline loops in Canada.

Difficulties in introducing an integrated system are recognized in relation to marketing a new product. A concentrated R & D effort along with detailed cost effective study are required to establish advantages and economic benefits of the integrated system, followed by a coordinated effort between mining companies, transportation agencies and users to implement the new system.

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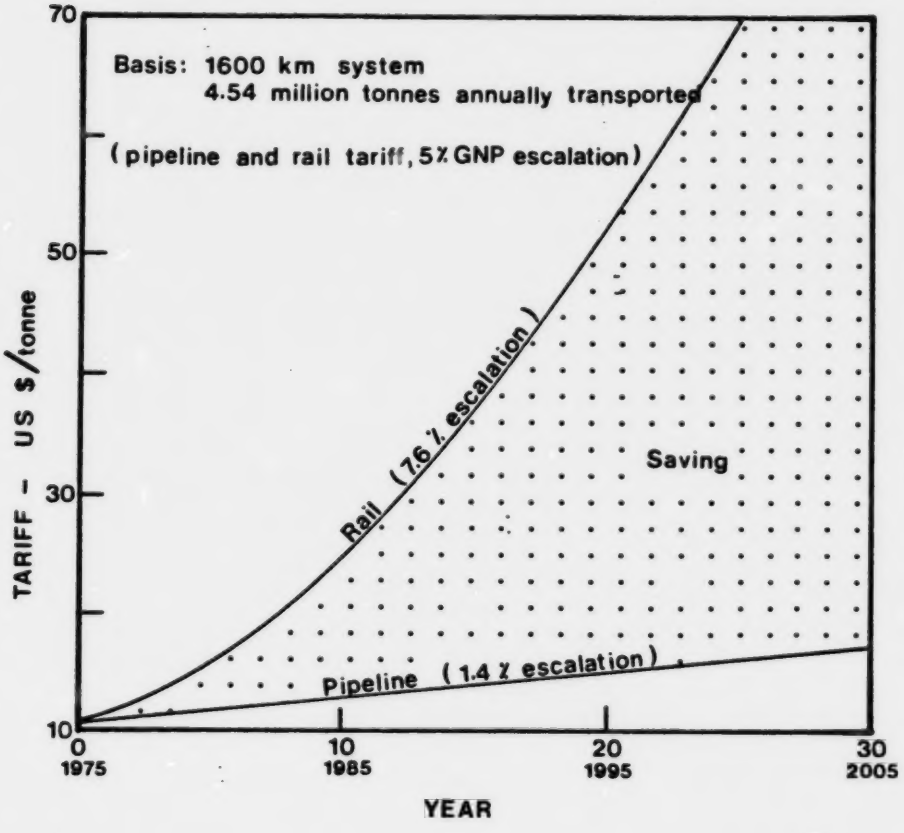

Fig. 1 - Tariffs as a function of time, between pipeline and railway transportation (28)

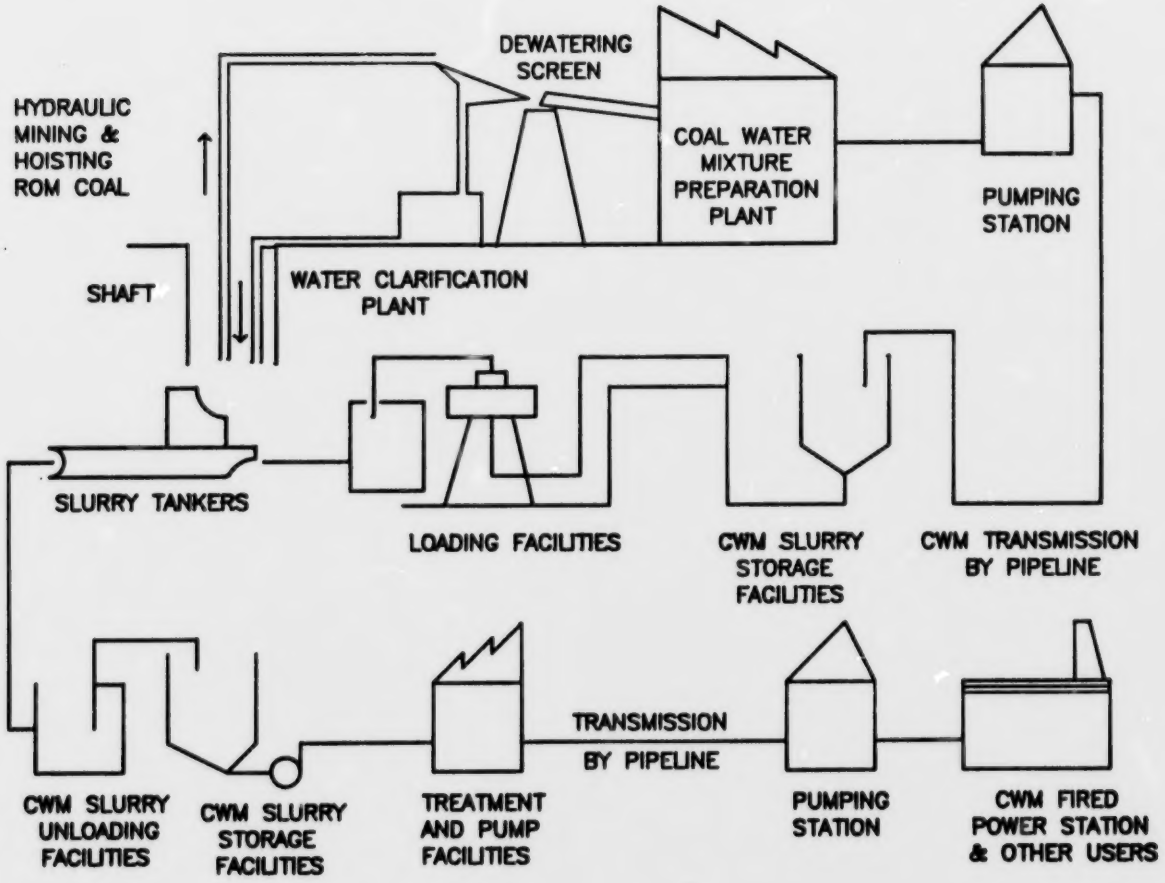

Fig. 2 - An integrated system for coal handling, beneficiation, transportation, and combustion of coal water mixture